Combination of Independent Component Analysis and Feature Extraction of ERP for Level Classification of Sustained Attention

Farnaz Ghassemi, *Student Member, IEEE*, Mohammad Hasan Moradi, *Member, IEEE*,
Mahdi Tehrani Doust, and Vahid Abootalebi, *Member, IEEE*.

Abstract— This paper investigates the relations between ERP features and visual sustained attention. Continuous Performance Test is used for determining sustained attention level. Fifty eight features were extracted from the 19-channel recorded signals. Twenty four Subjects were divided into three classes according to their attention level. LDA classifier is used and high accuracy (94%, 88% and 93% for each two classes) is achieved by using two features in classifying the test data. Obtained results are in agreement with the previous studies.

Keywords—Independent Component Analysis; Sustained Attention; Event Related Potential; LDA Classifier.

I. INTRODUCTION

Sustained attention refers to the ability to maintain a consistent behavioral response during continuous and repetitive processing of stimuli whose non-arousing qualities would otherwise lead to habituation and distraction to other stimuli [1,2].

Evaluation of attention has various applications such as diagnosis and treatment of diseases (e.g. ADHD), learning enhancement in classroom, attention investigation in infants and attention monitoring in critical activities such as aeronautical navigation.

Unfortunately common methods for measuring attention evaluate its manifestations. Direct measurement of Attention using brain signals, is important because it can eliminate excessive interfaces. Benefits of achieving such a system are: minimizing individual effects such as responding speed or processing ability, application for subjects with vision/auditory disorders and independence of a specific language or culture.

Since Electroencephalography/ Event Related Potential (EEG/ERP) is the most direct noninvasive method for investigating brain activities and consequently attention, thus its evaluation is interesting for neuroscientists in sustained attention studies.

Up to now, different studies have been carried out

regarding various types of attention and their relations with brain activities. Unfortunately, there are different states associated with sustained attention which are in broad use with varied ambiguous meanings such as arousal, alertness, vigilance and attention. This problem is investigated in [3] and it is mentioned that sustained attention can be used synonymously to vigilance and tonic alertness (not phasic alertness).

Makeig and coworkers investigated early and late ERPs during visual spatial attention and led to new grounds for attention extraction from brain signals by means of Independent Component Analysis (ICA) [4]. ICA is referred to the separation of independent sources which are mixed together with an unknown mixing matrix [5]. ICA method has been used in several studies [4,6] to separate sources with brain origin from other sources with artifactual origins.

One of the most popular tests for evaluating sustained attention is Continuous Performance Test (CPT) [7]. Obtained results on EEG/ERP study during CPT [8] showed that all subjects shared a progressive backshift of alpha rhythm during the accomplishment of the CPT test while beta and gamma activities were stronger in the right hemisphere than in the left. An intense and widespread decrease in EEG spectral power during test performing became visible in many subjects. Statistical analysis revealed that EEG activity correlates with the test behavioral results in many cerebral areas.

Another study on a similar test for sustained attention has found two main ERP components (N2 and P3) investigating whether a central inhibitory mechanism intervenes to prevent the preparation and/or execution of a motor response. N2 was detectable in the No-Go trials. P3 presented a different scalp distribution based on the type of trial [9].

This paper investigates the correlations between sustained attention level and ERP morphological features especially P3 characteristics and then evaluates the validity and efficiency of these features to classify sustained attention levels.

II. METHODS AND MATERIALS

A. CPT Task

This study is based on the Conners' CPT II test which is a "No-Go" CPT task. The subjects seated on a comfortable chair with a place for relaxing the head. The test was performed in a quiet and dimly lit room. The distance between the subjects' eyes and monitor (19 inch) was 75 ± 5 cm depending on their height. Different letters of English alphabet were presented randomly on the screen and subjects were required to click the left

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F. Ghassemi is with the Biomedical Engineering Faculty of Amirkabir University of Technology, Tehran, Iran (corresponding author, phone: (+98)912-326-0661; fax: (+98)21-6642-0672; e-mail: ghassemi@aut.ac.ir).

M. H. Moradi is with the Biomedical Engineering Faculty of Amirkabir University of Technology, Tehran, Iran.

M. Tehrani Doust is with the Psychology Department, University of Tehran, Tehran, Iran, and Institute for Cognitive Science Studies (ICSS), Tehran, Iran.

V. Abootalebi is with the Electrical Engineering Faculty of Yazd University, Yazd, Iran.

mouse button with the index finger of their dominant hand when any letter except the target "X" appeared. Subjects were instructed to respond as fast as they can, but also as accurately as possible.

The letters were 7.5 cm high and 7 cm wide which results in a 7° visual angle. They appeared white colored on a black background. The inter-stimulus intervals (ISIs) were 1, 2 or 4 seconds with a display time of 250ms. There were 6 blocks, with 3 sub-blocks each containing 20 trials. The order in which the different ISIs were presented varied between blocks. The experiment involved 360 stimuli: 36 X letters (No-Go stimuli) and 324 other letters (Go stimuli). The test took approximately 14 minutes to complete.

B. EEG Recordings

19-channel EEG was recorded with Ag/AgCl electrodes mounted in an electrode cap placed according to the international 10-20 standard (Fp1/Fp2, F3/F4, F7/F8, T3/T4, C3/C4, T5/T6, P3/P4, O1/O2, Fz/Cz/Pz). Average of A1 and A2 was used as reference. Three additional bipolar channels were used for vertical EOG recording, synchronization of CPT system with EEG signals and recording of subject's responses. For the last two pairs of channels, two independent isolator circuits were used for providing the subjects' safety and reducing noise. A 32-channel AC/DC amplifier (Walter) was used for data recording and PI-Winsor 3.0 for data acquisition. Amplifier band pass was 0.05–100 Hz and a 50 Hz notch filter was used for line noise reduction. The A/D sampling rate was 200 Hz. Impedance of all electrodes was kept below 5 K Ω .

C. Subjects

Twenty four volunteers (14 male) with average age of 29 ± 6.3 years participated in the experiment. Since financial incentives affect the sustained attention level [3], subjects were not paid to participate and they were just thanked with a small gift at the end of the experiment. All subjects were tested for handedness with Edinburgh test (1 left-handed). They had normal or corrected to normal vision. For evaluating generalization (as the test is in W/B), all subjects were checked for color-blindness with Ishihara test and one male was color-blind. For evaluating subject's Neuropsychological history SARs test was used and subjects were free of neurological disorders and were not taking any medication. All subjects gave their informed consent. The experiment was conducted in accordance with the Declaration of Helsinki.

D. ERP Extraction

Signals were filtered by a 0.1-85 Hz band pass filter. Combination of Efficient Variant of Fast ICA (EFICA) and ¹ Efficient Weights Adjusted SOBI (EWASOBI) was used as the ICA method [10]. Time, frequency and spatial characteristics of the resulted independent components were studied and proper components with brain origins which were physiologically plausible were selected manually (from 1 to 6 components in different subjects or ISIs). Then only these components were returned to electrode space.

Four groups were considered for each subject: Target stimuli (X), Non-target stimuli (nX), Correct answered target stimuli (CX, which is the X that subject did not respond) and Non-correct answered target stimuli (nCX).

Twelve ERPs were extracted for each subject for different ISIs (1, 2 and 4s) and groups (X, nX, CX, nCX). Period of epochs were considered 200 ms before till 1000 ms after stimuli onset and ERPs were achieved by averaging epochs time-locked to stimuli onset.

The P3 window was considered at 350–650ms after stimulus onset based on the prior researches [9, 11]. Amplitude of P3 is defined as the difference between the mean pre-stimulus baseline voltage and the largest positive-going peak of the ERP waveform within a time window (e.g. 350-650ms)[11]. Amplitude and latency of P3 were both computed.

E. Features and Classifier

Defined features included two general groups of amplitude and delay of P3 which were calculated for different ISIs and groups. In addition, features were defined for absolute ISIs or relative to each other. Therefore 48 features ($2 \times 3 \times 4 \times 2$) were considered for each channel.

Subjects divided to three classes according to their attention level, 7 in high (H), 7 in medium (M) and 10 in low (L) attention class. For investigating the relation between these features and CPT results, Pearson correlation was calculated between attention levels and features for different channels. Fifty eight features had significant correlation (P-value<0.05) with attention levels which are expressed in Table. 1. Symbol "A" is used for amplitude and "D" for delay of P3. The phrase in the parenthesis explains the group and subscript indices express the related ISI of calculated ERP which could be absolute or relative. For example, $D_{S1}(CX)$ means the delay of P3 on ERP calculated for 1s ISI in correct X group or $A_{S24}(nCX)$ means the difference of amplitudes of P3 on ERP

Table 1. Feature Characteristics.

Features which had significant correlation with sustained attention level are defined. For example $A_{S24}(nCX)$ means the difference of amplitudes of P3 on ERP calculated for 2s and 4s intervals in non-correct X group. The left number under each feature expresses its correlation coefficients with sustained attention level while the right number is that features number.

Channel	Feature											
	Correlation / Feature No											
Fp1	$D_{S2}(X)$	$D_{S42}(nX)$										
	0.42	1	-0.42	2								
Fp2	$A_{S42}(nX)$	$D_{S1}(CX)$	$D_{S2}(CX)$									
	-0.42	3	0.45	4	0.47	5						
F7	$D_{S2}(X)$	$D_{S2}(CX)$	$D_{S41}(nCX)$									
	0.41	6	0.46	7	-0.41	8						
F8	$D_{S1}(X)$	$A_{S42}(nX)$	$D_{S42}(nCX)$									
	0.41	9	-0.41	10	-0.46	11						
F3	$D_{S1}(X)$	$D_{S1}(nX)$	$A_{S1}(CX)$	$D_{S1}(CX)$								
	0.41	12	0.63	13	-0.52	14	0.43	15				
F4	$A_{S1}(X)$	$A_{S1}(CX)$	$D_{S1}(CX)$									
	-0.41	16	-0.51	17	0.44	18						
T3	$D_{S1}(nX)$											
	0.44	19										
T4	$D_{S1}(X)$	$D_{S1}(CX)$										
	0.49	20	0.46	21								
C3	$D_{S1}(X)$	$A_{S1}(nX)$	$D_{S1}(nX)$	$D_{S1}(CX)$								
	0.45	22	-0.51	23	0.56	24	0.51	25				
C4	$A_{S1}(X)$	$D_{S1}(X)$	$D_{S2}(X)$	$D_{S4}(X)$	$D_{S2}(nX)$	$A_{S1}(CX)$	$D_{S1}(CX)$					
	-0.51	26	0.49	27	0.42	28	0.43	29	0.45	30	-0.68	31
T5	$D_{S1}(X)$	$D_{S4}(X)$	$D_{S1}(CX)$									
	0.46	33	0.44	34	0.48	35						
T6	$D_{S41}(X)$											
	0.42	36										
P3	$D_{S1}(X)$	$A_{S1}(CX)$	$D_{S1}(CX)$									
	0.43	37	-0.42	38	0.56	39						
P4	$D_{S4}(X)$	$D_{S41}(nX)$										
	0.41	40	0.44	41								
O1	$D_{S42}(X)$	$D_{S41}(nCX)$	$A_{S42}(nCX)$									
	0.46	42	0.45	43	0.42	44						
O2	$D_{S42}(X)$	$D_{S42}(nX)$										
	0.43	45	-0.45	46								
Fz	$A_{S1}(X)$	$D_{S2}(X)$	$D_{S1}(nX)$	$A_{S1}(CX)$	$D_{S1}(CX)$	$D_{S2}(CX)$						
	-0.45	47	0.41	48	0.49	49	-0.61	50	0.65	51	0.49	52
Cz	$D_{S1}(X)$	$A_{S1}(CX)$	$D_{S1}(CX)$									
	0.61	53	-0.50	54	0.60	55			0.55	56	0.45	57
											0.49	58

calculated for 2s and 4s ISIs in non-correct X group.

In the next step, Linear Discriminant Analysis (LDA) classifier was used for discrimination of each two classes. According to Leave One Out (LOO) method, one subject's data was considered as test data and the classifier was trained based on others, then it was evaluated on the test data. This procedure was repeated for all subjects and accuracy is achieved by the ratio of correct classifications to total number of subjects. This test was performed for each feature and then repeated for all combinations of two features.

III. RESULTS

Grand average ERP for all subjects is illustrated in fig. 1. As it can be seen, amplitude of P3 is obviously larger in target (X) than non-target (nX) stimuli. These curves are smoothed with a 12 Hz filter. Fig. 2 demonstrates the topographic map of ERP at different delays (columns) for 1s ISI in correct X stimuli. Each row contributes to one attention level. It can be seen that there are some outstanding differences between classes. These maps are obtained using EEGLAB software [12].

Calculated correlations between CPT results and defined features showed a significant relation (P -value < 0.05) at all locations of the scalp (Table 1). Accuracy for classification on test and train data with one and two features are shown in Table 2. The best result for classification between H/L class on test data (94%) is obtained with combination of features 43 and 52 which are related to $D_{S41}(nCX)$ and $D_{S2}(CX)$ according to table 1. The best result for classification between H/M class on test data (88%) is obtained with combination of features 43 and 51 which are related to $D_{S41}(nCX)$ and $D_{S1}(CX)$ while the best result for classification between M/L class on test data (93%) is obtained with combination of features 11 and 58 which are related to $D_{S42}(nCX)$ and $D_{S1}(CX)$. The accuracy for classification of all classes is 79% which obtained by combination of features 43 and 23 ($D_{S42}(nCX)$ and $A_{S1}(nX)$). These percents are summarized in fig. 3.

IV. DISCUSSION

The P3 peak on target stimuli (X) was clearly observed for all subjects (irrespective of answers correctness) and this P3

observation on unusual target stimuli is in complete agreement with previous studies [9,11,13]. This peak was obviously larger on target than non-target stimuli as can be seen in fig.1. This evident could be due to characteristics of task, complete perception of task for subjects and/or the proper ratio of target stimuli to total stimuli (1 to 10).

Independent components for EEG signals were calculated and best components were selected based on their time, frequency and spatial characteristics. Calculated correlations confirm the significant relations between CPT result and some ERP features at all scalp locations but it was stronger at C4, C3, Cz, F3, F4, Fz, P3 and Pz. Best results of classification in all classes (79%) was obtained with combination of two features, one amplitude and one delay ($D_{S42}(nCX)$ and $A_{S1}(nX)$), while in classification of each two classes (H/L 94%, H/M 88%, M/L 93%), these two features were both for delay but one on CX group and the other on nCX group ($D_{S41}(nCX)$ - $D_{S2}(CX)$, $D_{S41}(nCX)$ - $D_{S1}(CX)$, and $D_{S42}(nCX)$ - $D_{S1}(CX)$ respectively). Consequently results represent a significant relation between CPT result and some parameters of brain signals which can be used in evaluating the level of attention.

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Figure 1. Grand average ERP for all subjects.

ERPs for 1s interval are illustrated with dash blue line, ERPs for 2s interval are illustrated with dash-dot red line and ERPs for 4s interval are illustrated with solid green line. Four different groups of ERP (X, nX, CX, nCX) are demonstrated in distinct subplots. Amplitude of P3 is obviously larger in target (X) than non-target (nX) stimuli.

Table 2. The accuracy achieved with LDA classifier.
The accuracy is calculated for test and train data for classification of each two classes with 1 feature (first three lines) and 2 features (last three lines). Last column is the average of all classifications (3 cases) for each feature or combination of features.

Figure 2. Topographic maps for 1s ISI in correct X stimuli at different time delays according to target presentation.

First row demonstrates the grand average ERP in High attention subjects and the grand average ERP in Medium and Low attention subjects are plotted in middle and down rows consequently. Maximum amplitude (marked on color bar of each plot) and delay of peak are different among classes.

	High / Low			High / Medium			Medium / Low			ALL		
	Feature No	Test	Train	Feature No	Test	Train	Feature No	Test	Train	Feature No	Test	Train
1 Feature	53	88.24	92.83	19	70.59	72.86	23	78.57	84.69	53	73.25	74.99
	1	88.24	91.30	41	70.59	72.37	53	78.57	78.57	58	72.83	72.22
	Max Train		92.8	Max Train		99.7	Max Train		84.7	Max Train		75.0
2 Features	43	52	94.12	96.57	43	51	88.24	89.58	11	58	92.86	92.86
	18	38	94.12	95.00	18	51	82.35	82.86	22	47	92.86	92.86
	Max Train		90.3	Max Train		26.3	Max Train		86.1	Max Train		81.8

Figure 3. Chart of achieved accuracy.

The front row shows the accuracies achieved with one feature and the back row demonstrates accuracies achieved with two features.

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